



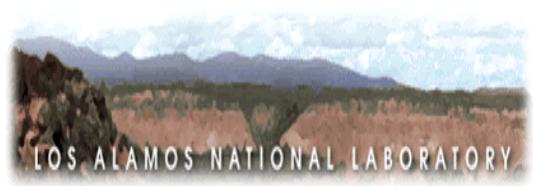
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**On Relativistic Electrons During
Magnetic Storms:
Analysis with Salammbô Code,
Comparison to In Situ Data and
Superposed Epoch**

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Contents



- A. Introduction
- B. Rationale
- C. The Salammbô model
- D. “Story Line”
- E. Satellites / Instrumentation
- F. Salammbô Run for September 1998 storm
- G. Salammbô Run for October 1998 storm
- H. Superposed Epoch Analysis Method
- I. Superposed Epoch Analysis Salammbô
- J. Superposed Epoch Analysis ULF
- K. Summary

A1. Introduction



Some features during some storms are consistent with each of the mechanisms put forward to explain the relativistic flux profiles observed after storms:

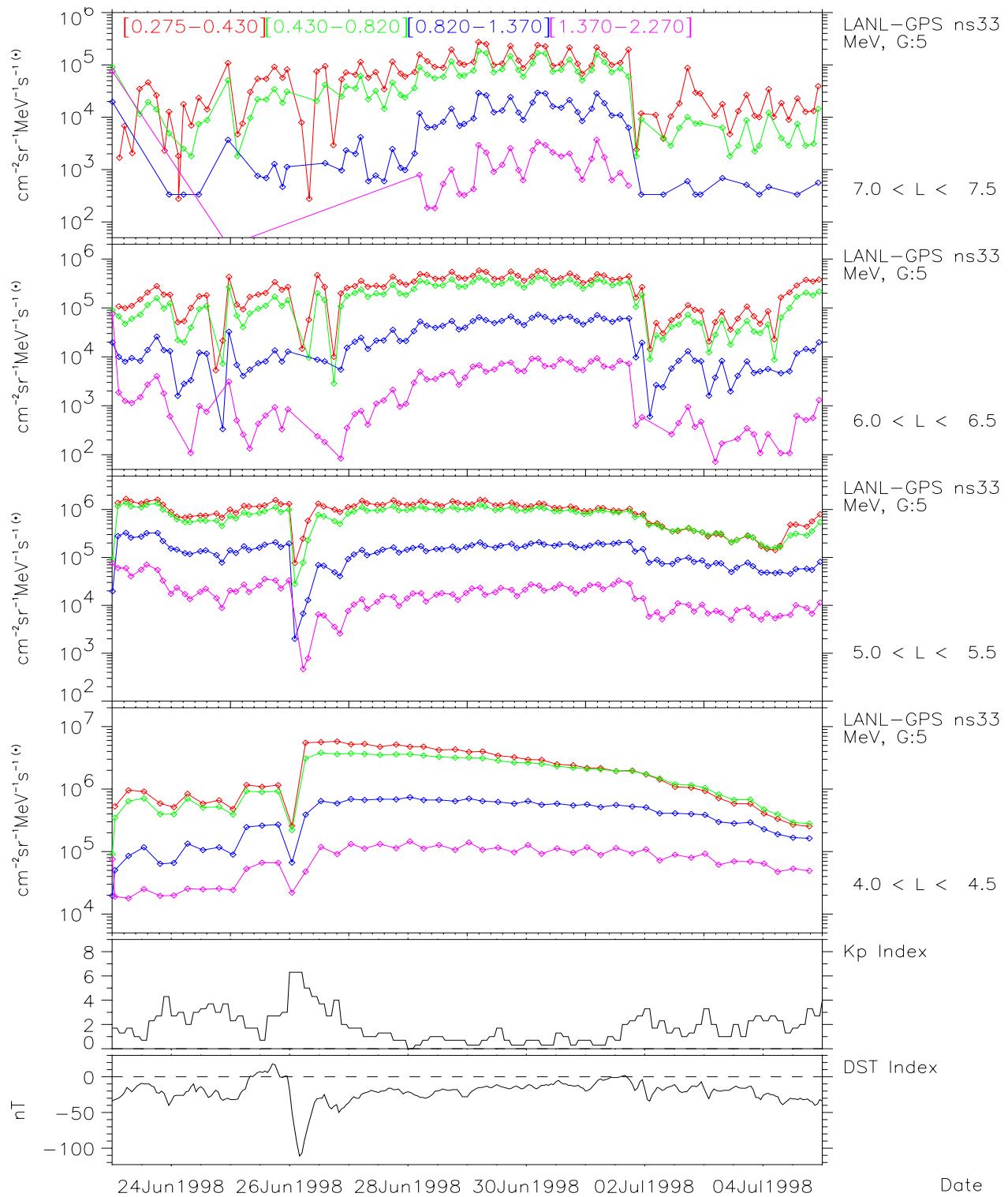
- Acceleration (recirculation) by ULF waves (Hudson, Liu)
- Injection by substorms (Ingraham)
- Acceleration (recirculation) by hiss at the plasmapause (Bourdarie, Boscher)
- Radial transport alone (Cayton, Hilmer)

These ideas have not yet lead to a consistent paradigm that can be applied to the existing large variety of observed storms.

This has lead to the infamous phrase:

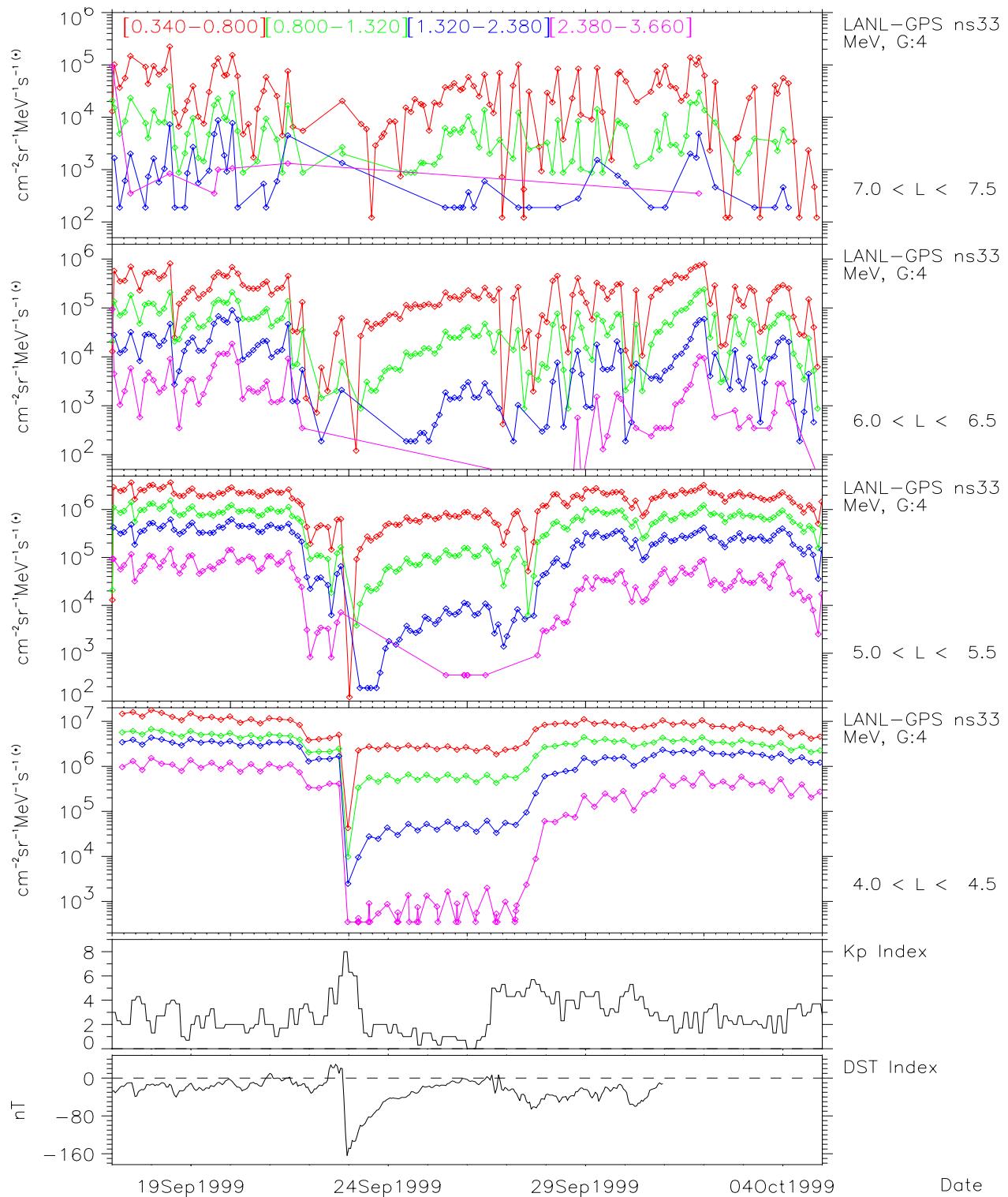
”If you’ve seen one storm –
you’ve seen one storm”.

A2. Storm Example (1) GPS ns33 June 1998

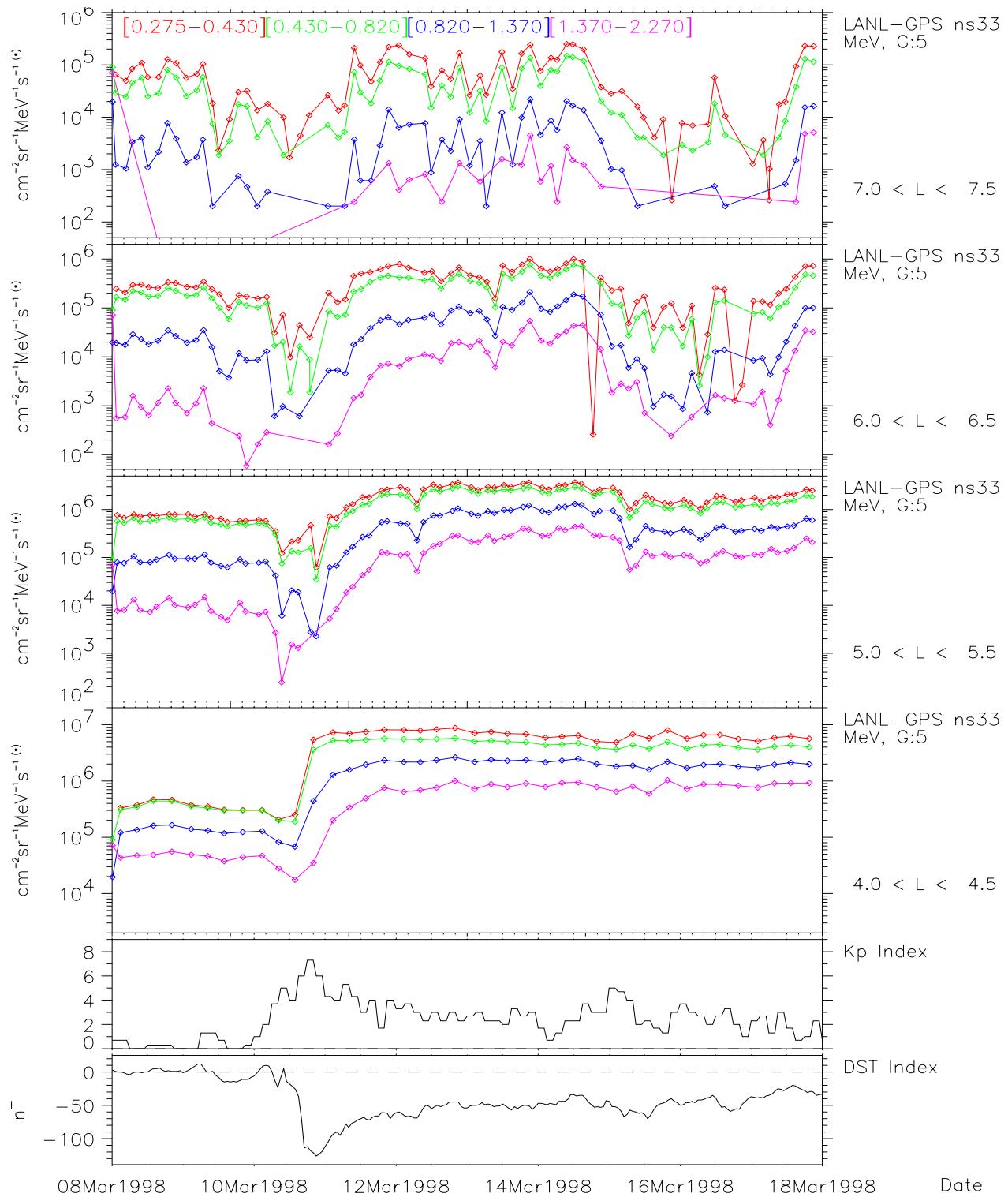


A3. Storm Example (2)

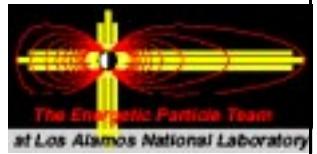
GPS ns33 September 1999



A4. Storm Example (3) GPS ns33 March 1998



B. Rationale



Use the physical principles embedded in the Salammbô code and the controlling parameters that are inputs to the code, and ask the question:

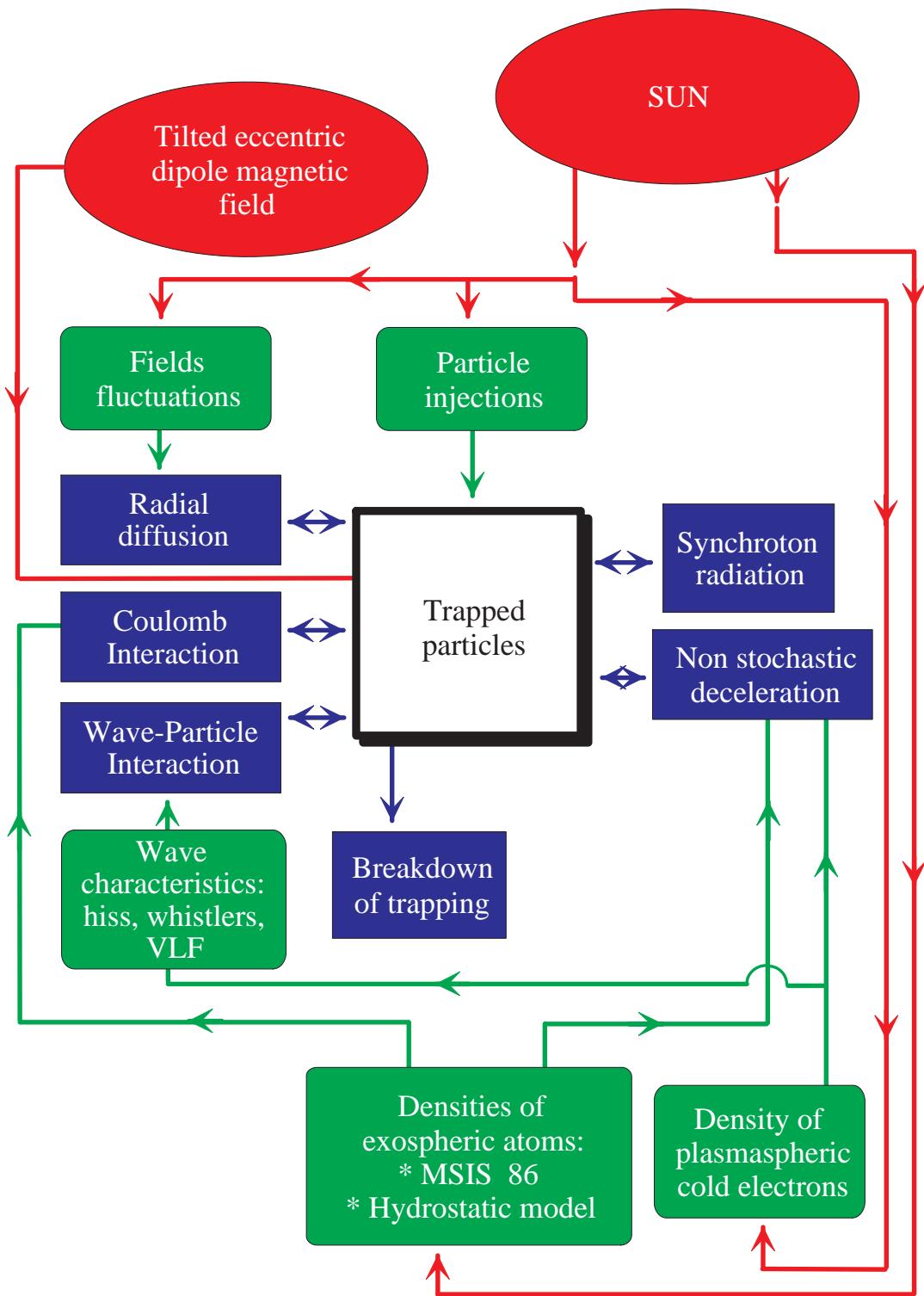
“Can we understand or even predict the general behavior of ANY storm, given the time sequence of the input parameters?”

Central to this question is the assumption that to understand individual storms the time-history is more important than the absolute value of any one given input parameter.

Test this on the Salammbô code mechanism and on ULF waves as a controlling factor for relativistic electron enhancements.



C1. Salammbô block diagram





C2. Salammbô operation

- Models all physical processes in terms of diffusion.
- parameterization in terms of Kp:
 - Radial diffusion coefficients
 - Plasmapause position
- Boundary condition is taken from geosynchronous measurements.
- Radial transport is driven by electric and magnetic field fluctuations.
- Wave particle interactions occur mainly near the plasmapause.
- Acceleration of electrons is modeled by a tight recirculation in the vicinity of the plasmapause
 - thus the location is controlled by Kp.

D. Salammbô “Story Line”



Rapid losses occur at onset down to $L=4$. Degree and depth of refilling in the main phase depends on diffusion strength, i.e. the behavior of K_p immediately after onset. Higher diffusion \rightarrow deeper injection by higher energy electrons.

Appearance of a two day delayed peak at geo depends on the effectiveness of the acceleration at the plasmapause in competition with the outside source plus diffusion strength during the main phase:

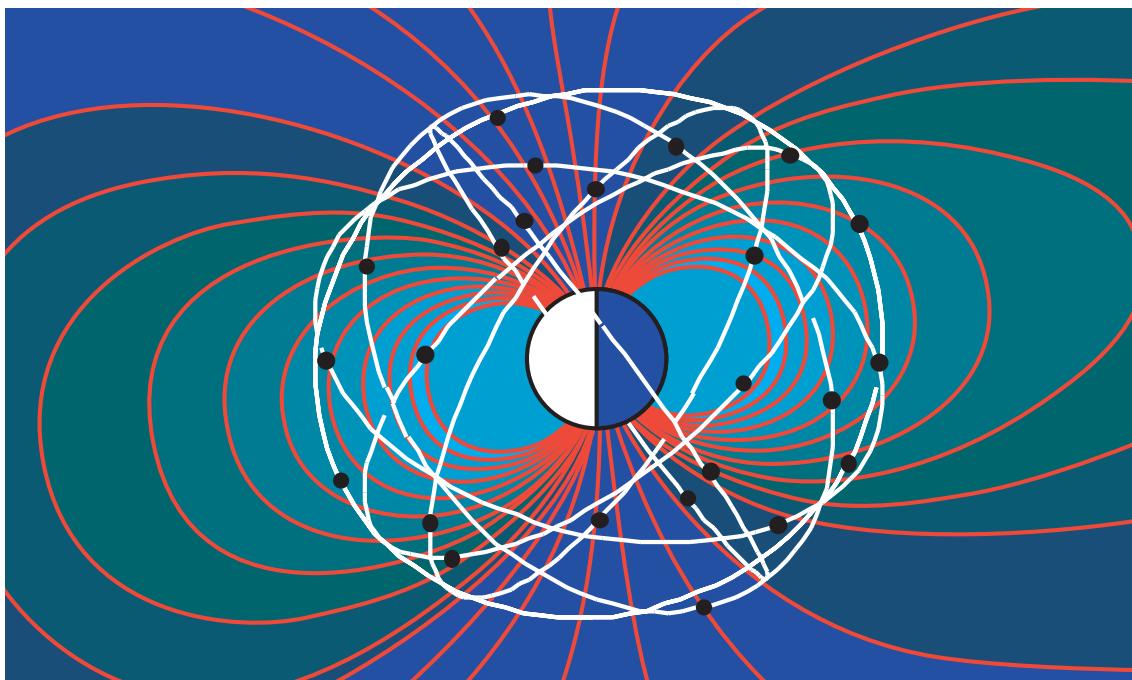
- Diff. to high plus source to high: internal source “swamped”, no effect.
- Diff. moderate plus high source: small effect from internal source.
- Diff. moderate plus low source: maximum effect of internal source at geo.



E1. GPS Satellites

Energetic particle sensors for the GPS program:

200 keV – 10 MeV electrons
9 MeV – 60 MeV protons



GPS ns08	1983 – 1984	BDD-I
GPS ns10	1984 – 1992	BDD-I
GPS ns18	1990 – 1995	BDD-II
GPS ns24	1991 – present	BDD-II
GPS ns28	1992 – 1996	BDD-II
GPS ns33	1996 – present	BDD-II
GPS ns39	1993 – present	BDD-II

E2. Correcting GPS Fluxes to equator

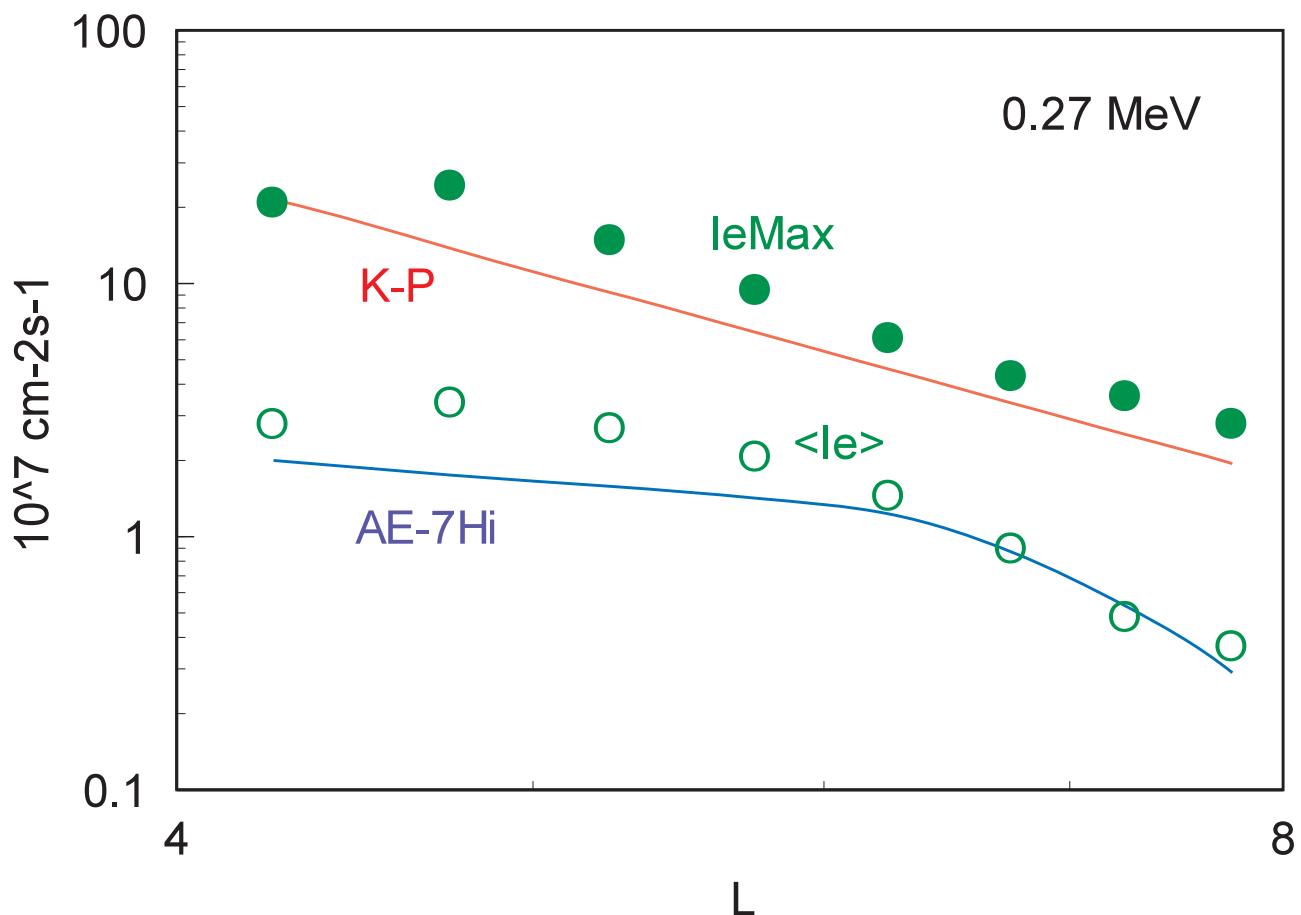


Lower fluxes at higher magnetic latitude can be corrected to the equator:

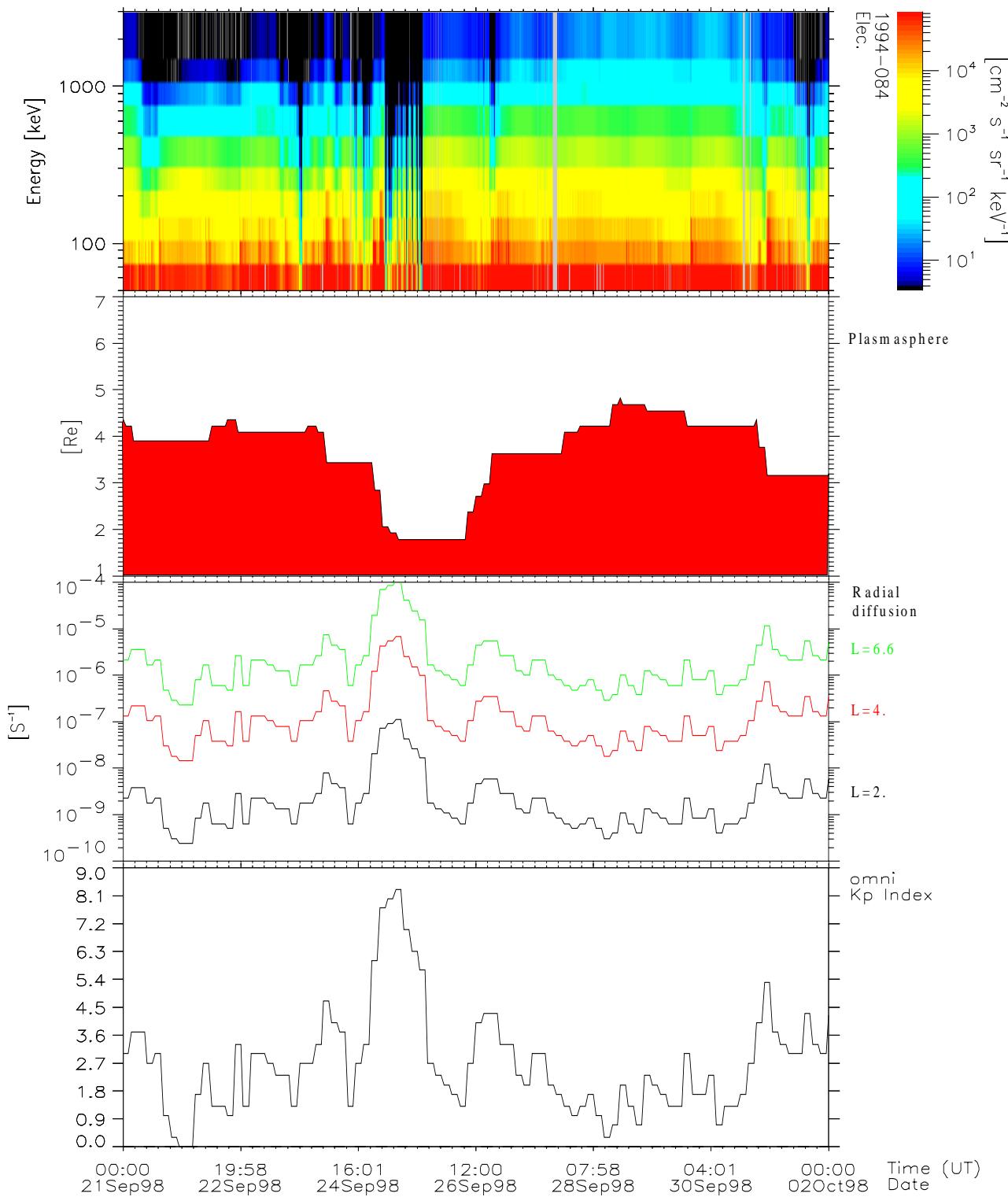
$$J(B_e)/J(B) = (B/B_e)^s, \quad j \sim \sin^2 s \alpha_e, \quad s \sim 0.5.$$

$$\text{GPS orbit + dipole: } (B/B_e) \sim (L/4.2)^{3.7}$$

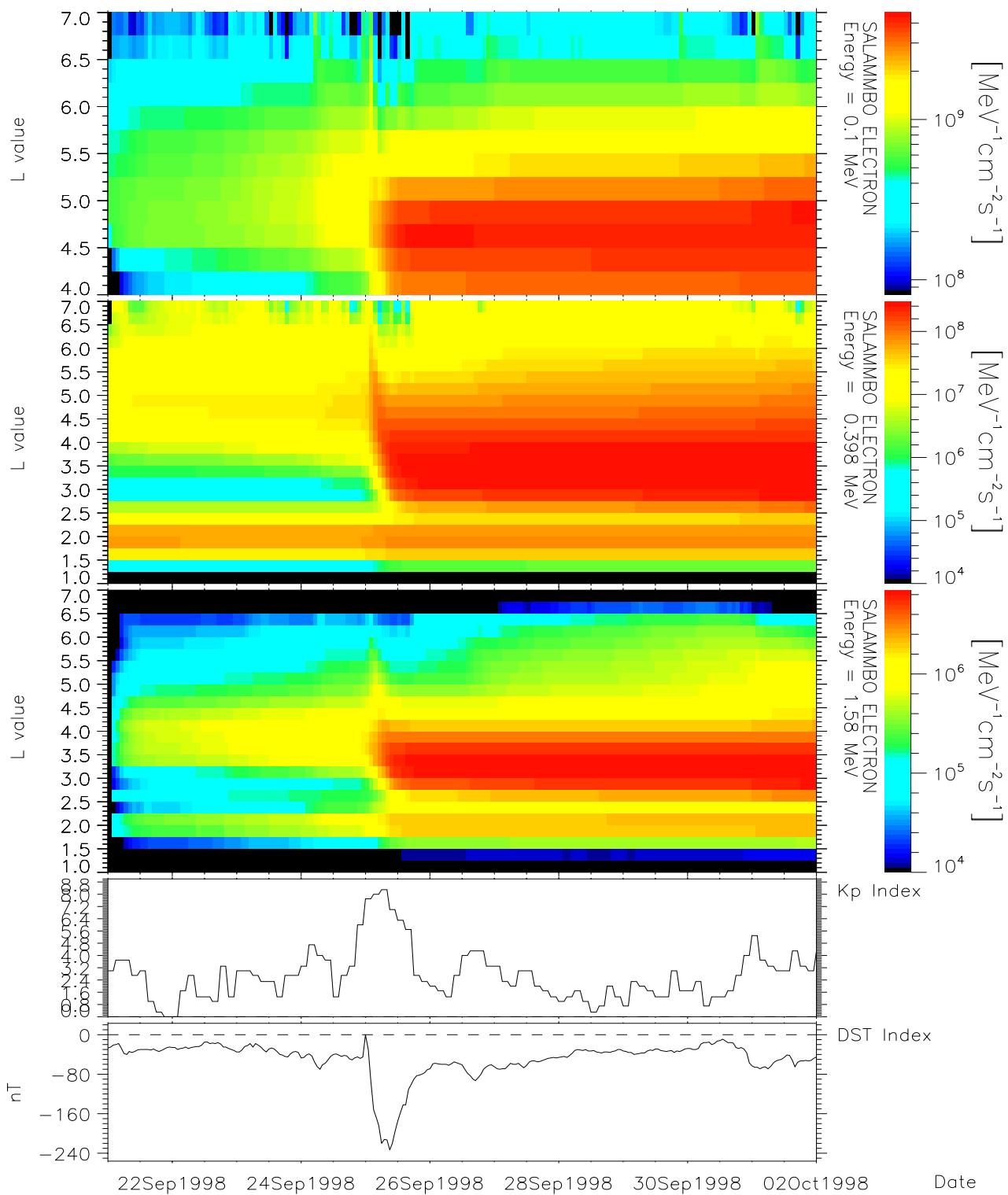
$$\text{Correction is then: } I_e \sim I(L/4.2)^{3.7s}.$$



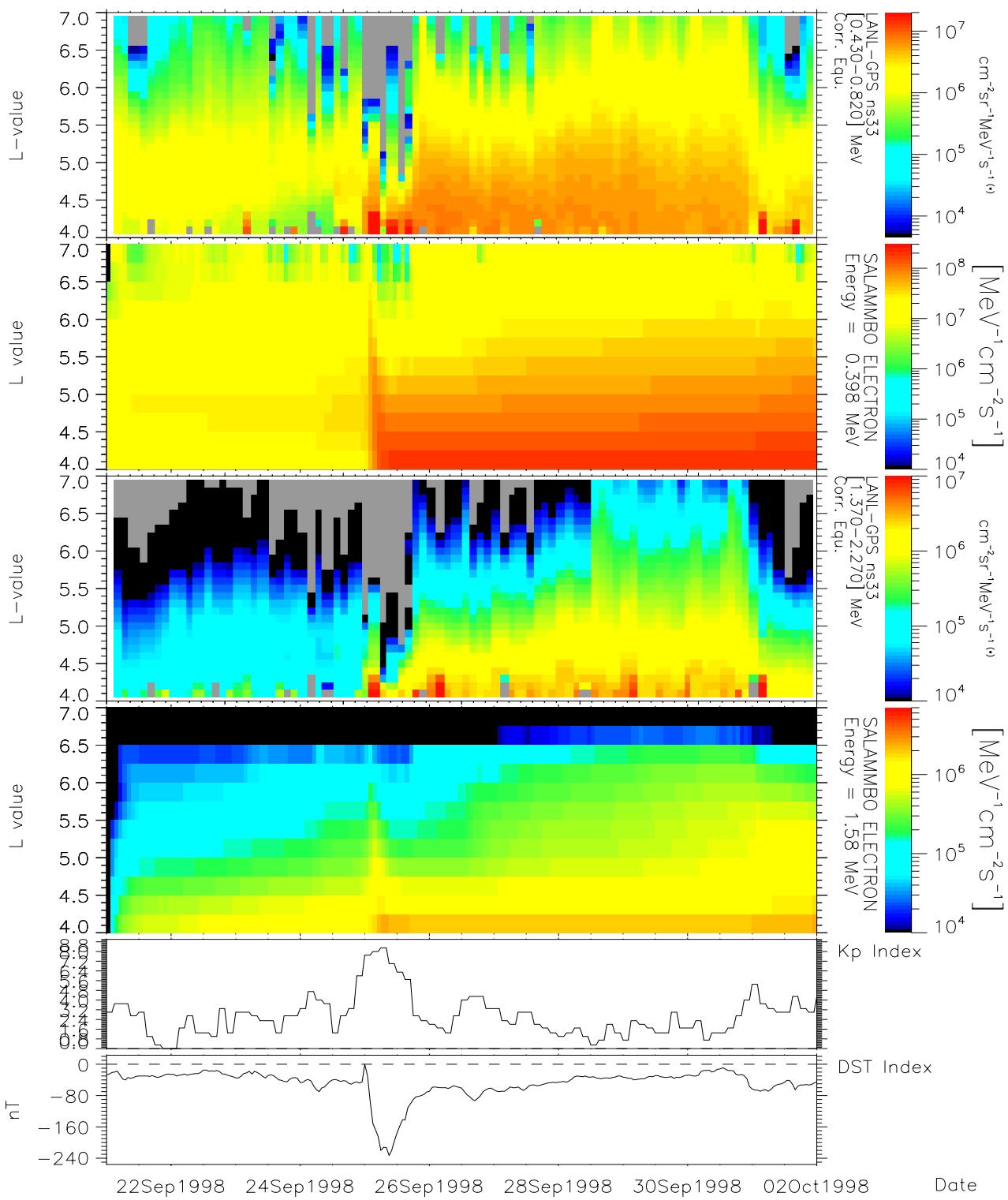
F1. Salammbô Run for September 1998 storm - Inputs



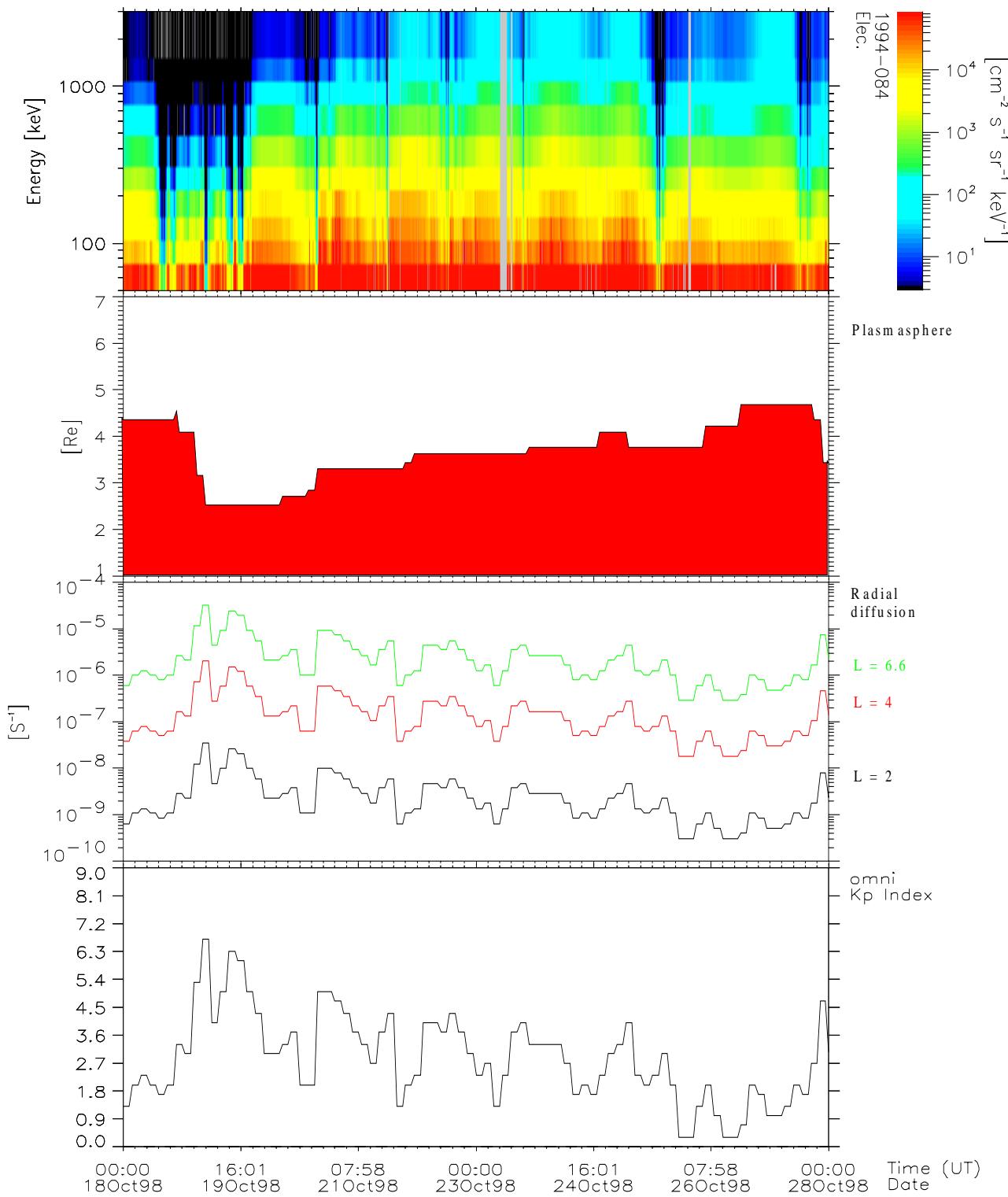
F2. Salammbô Run for September 1998 storm - Results



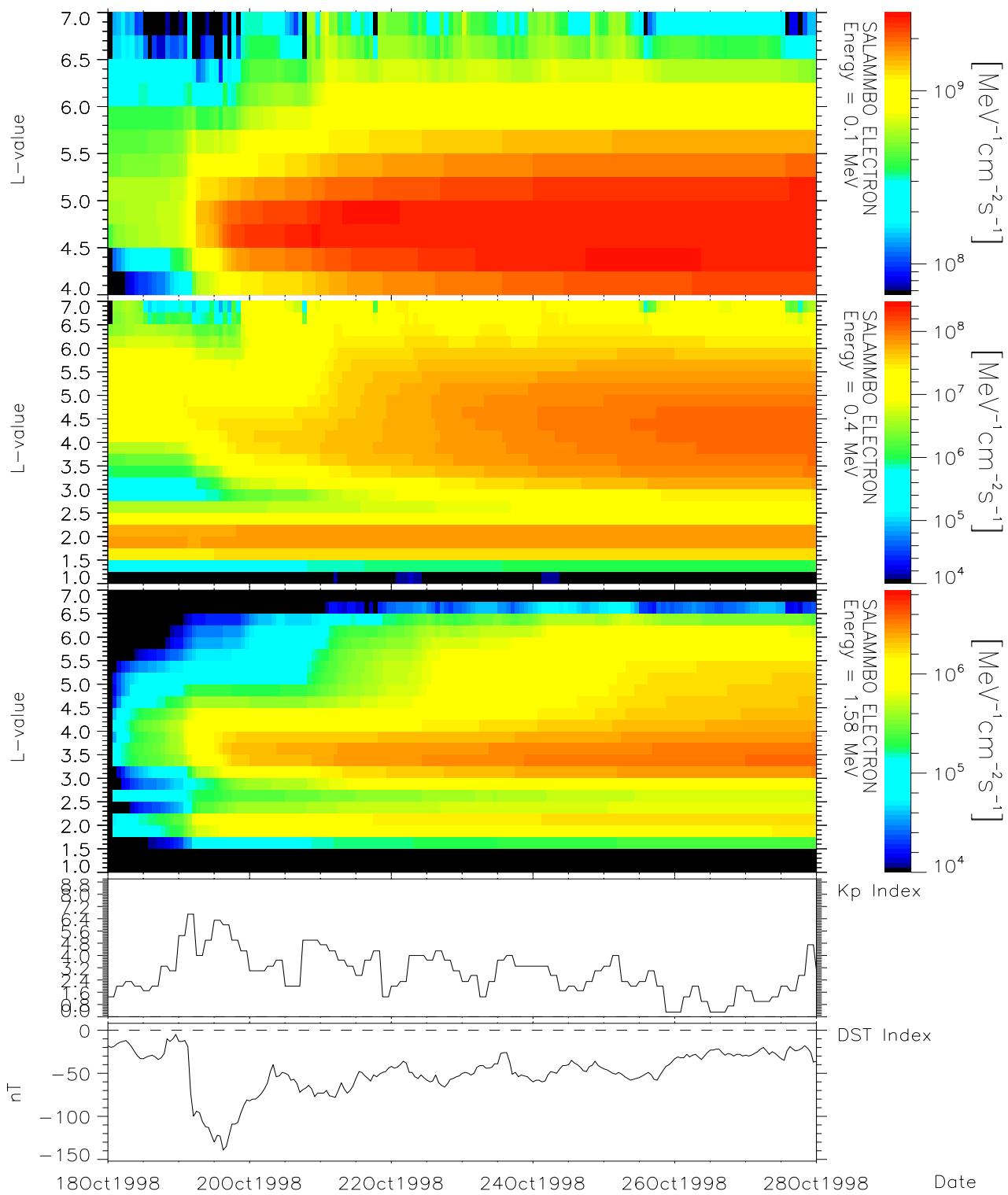
F3. September 1998 storm Salammbô – GPS comparison



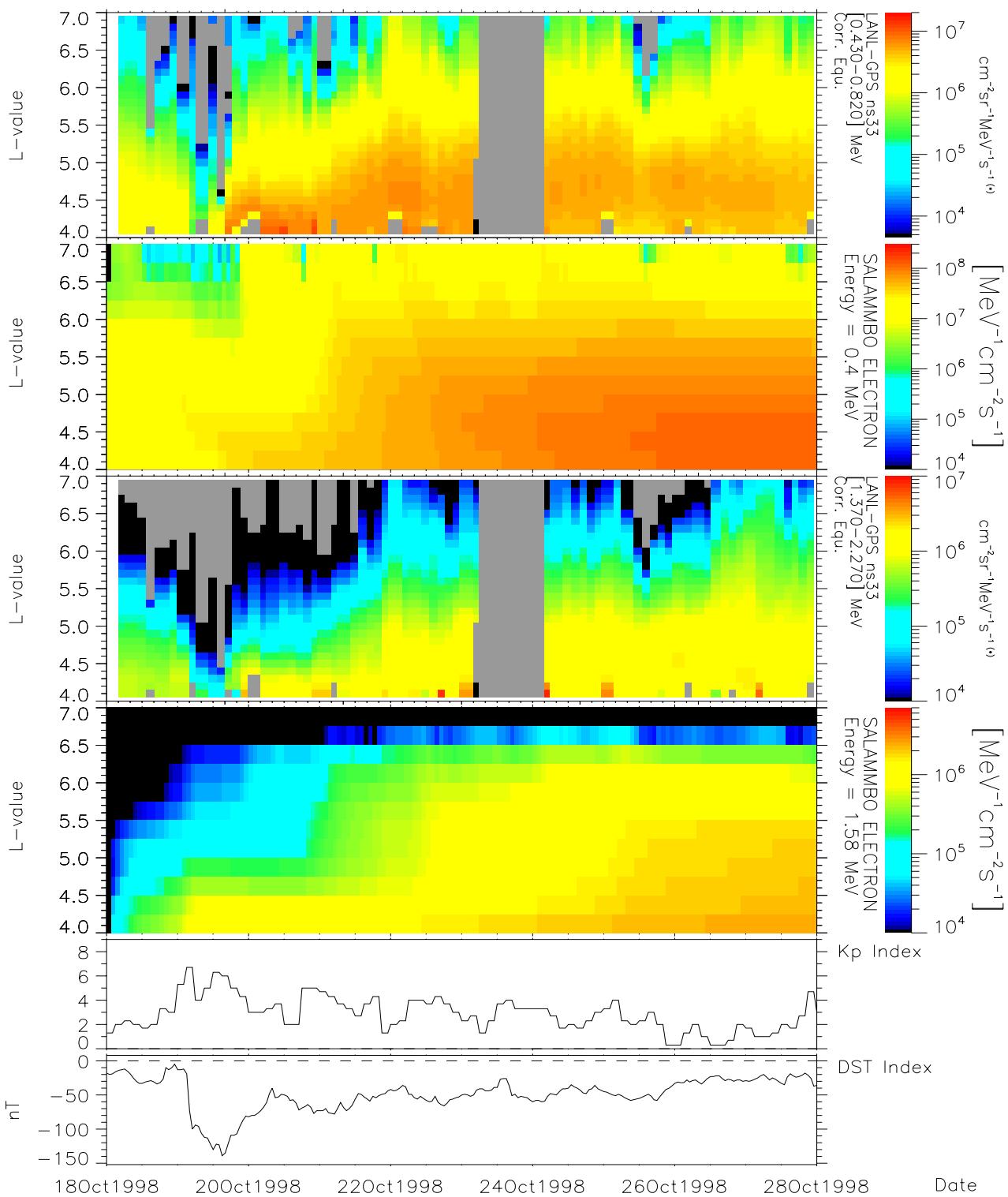
G1. Salammbô Run for October 1998 storm - Inputs



G2. Salammbô Run for October 1998 storm - Results



G3. October 1998 storm Salammbô – GPS comparison



H. Superposed Epoch Method



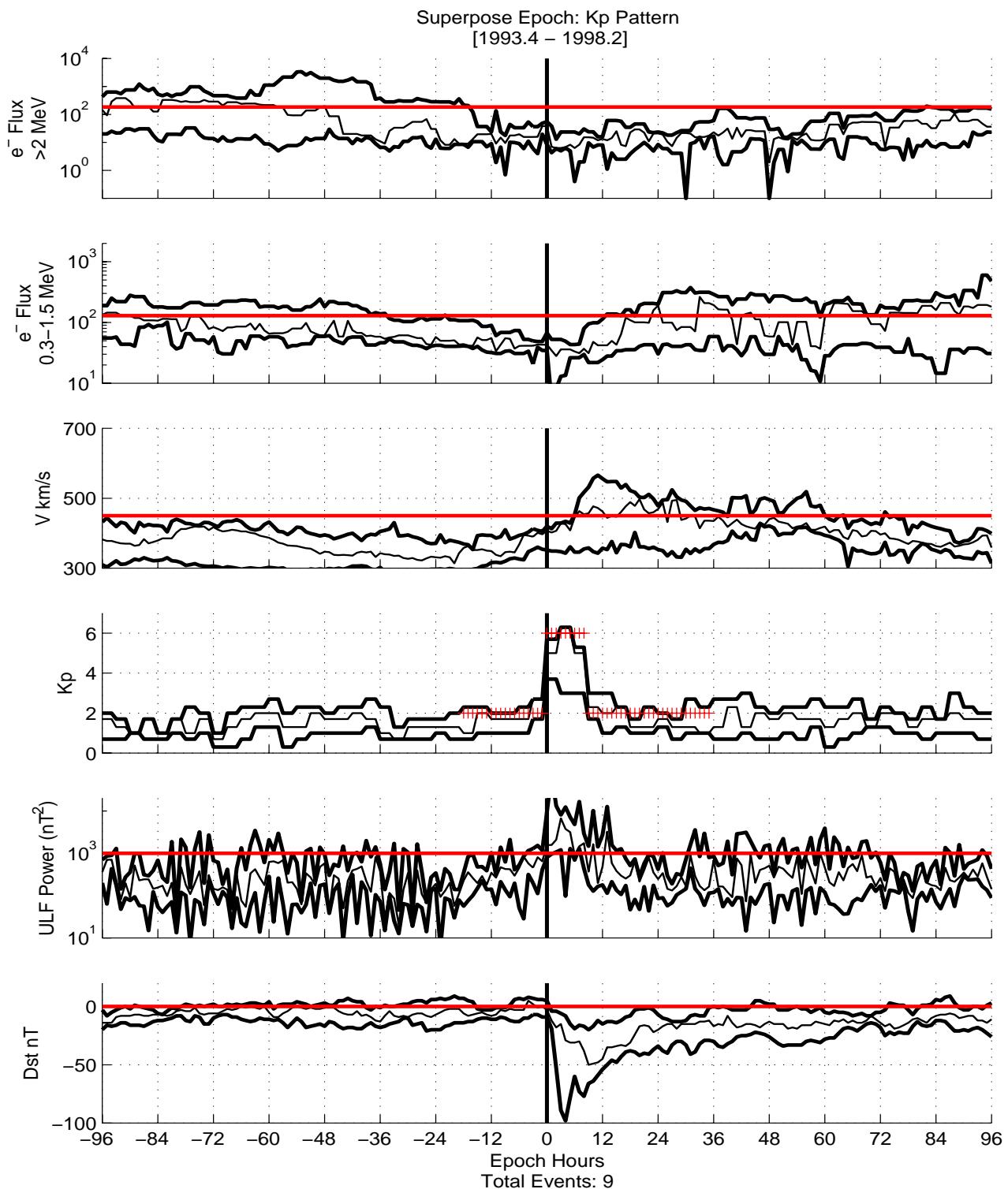
A superposed epoch study which uses the beginning of a specified time sequence in a variable as zero epoch, has been performed. We look here for a series of storms that had similar profiles in Kp and also ULF wave power.

The plots show the results for a synthesized geosynchronous satellite at noon measuring the $> 2\text{MeV}$ electron flux, together with a range of solar wind parameters, Kp and Dst (Poster by Paul O'Brien).

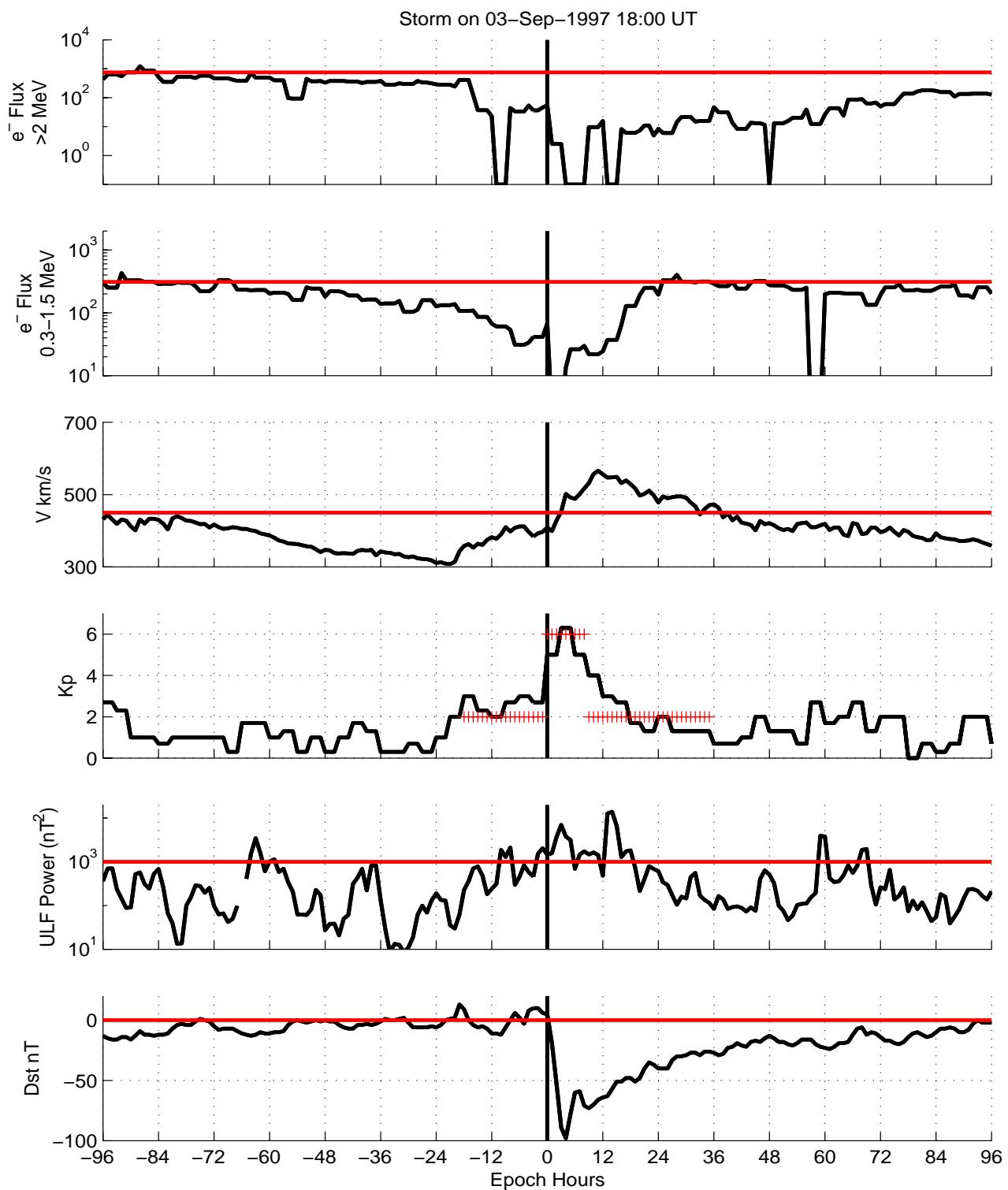
Profiles were chosen based on Salammbô operation. The first was a delta function in Kp - above a threshold for a certain length of time, followed by low Kp for several days.

The second profile has a high Kp initially, followed by, high slowly decreasing values of Kp.

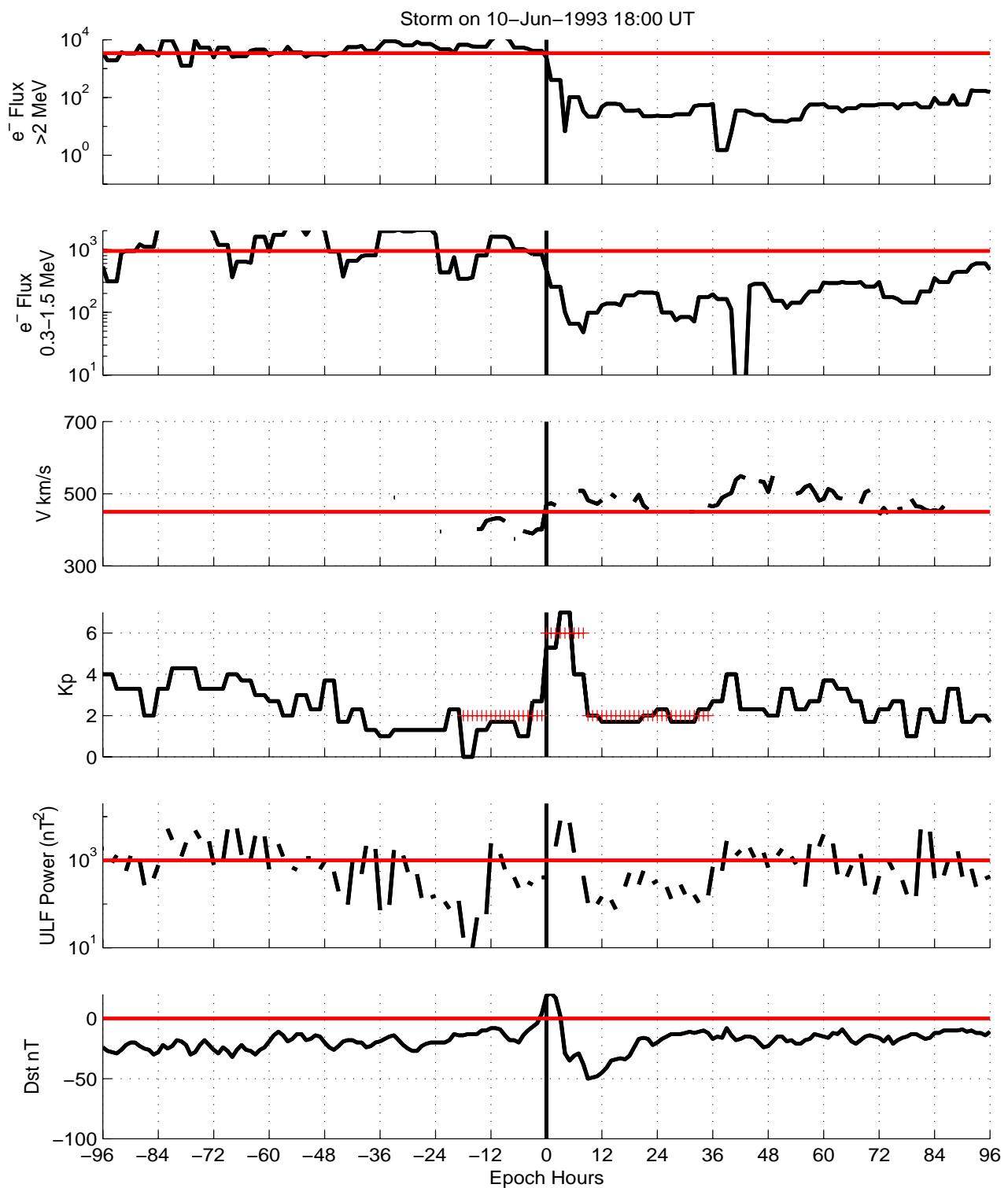
I1. K_p Top Hat Superposed Epoch



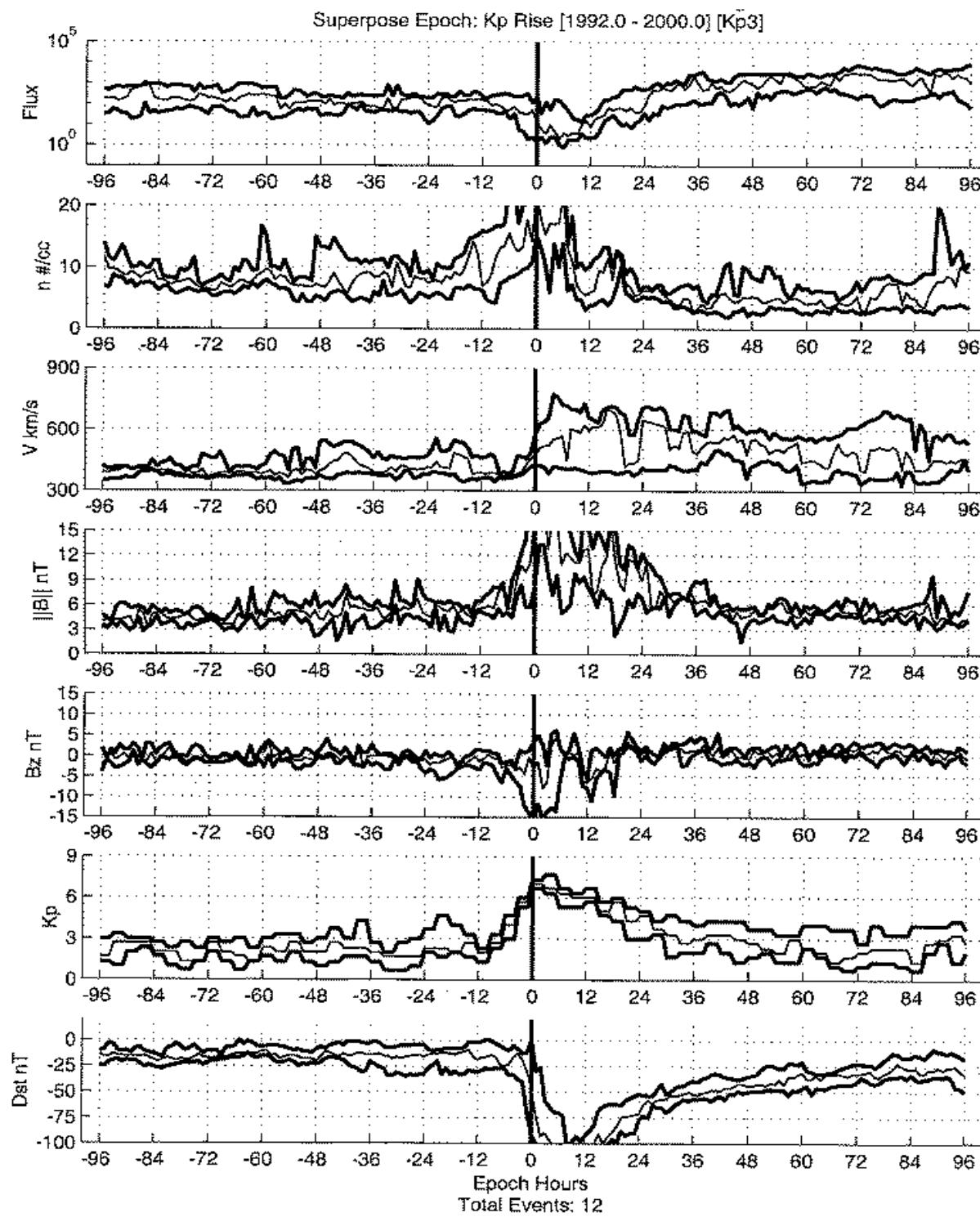
I2. K_p Top Hat Example 1997/09/03



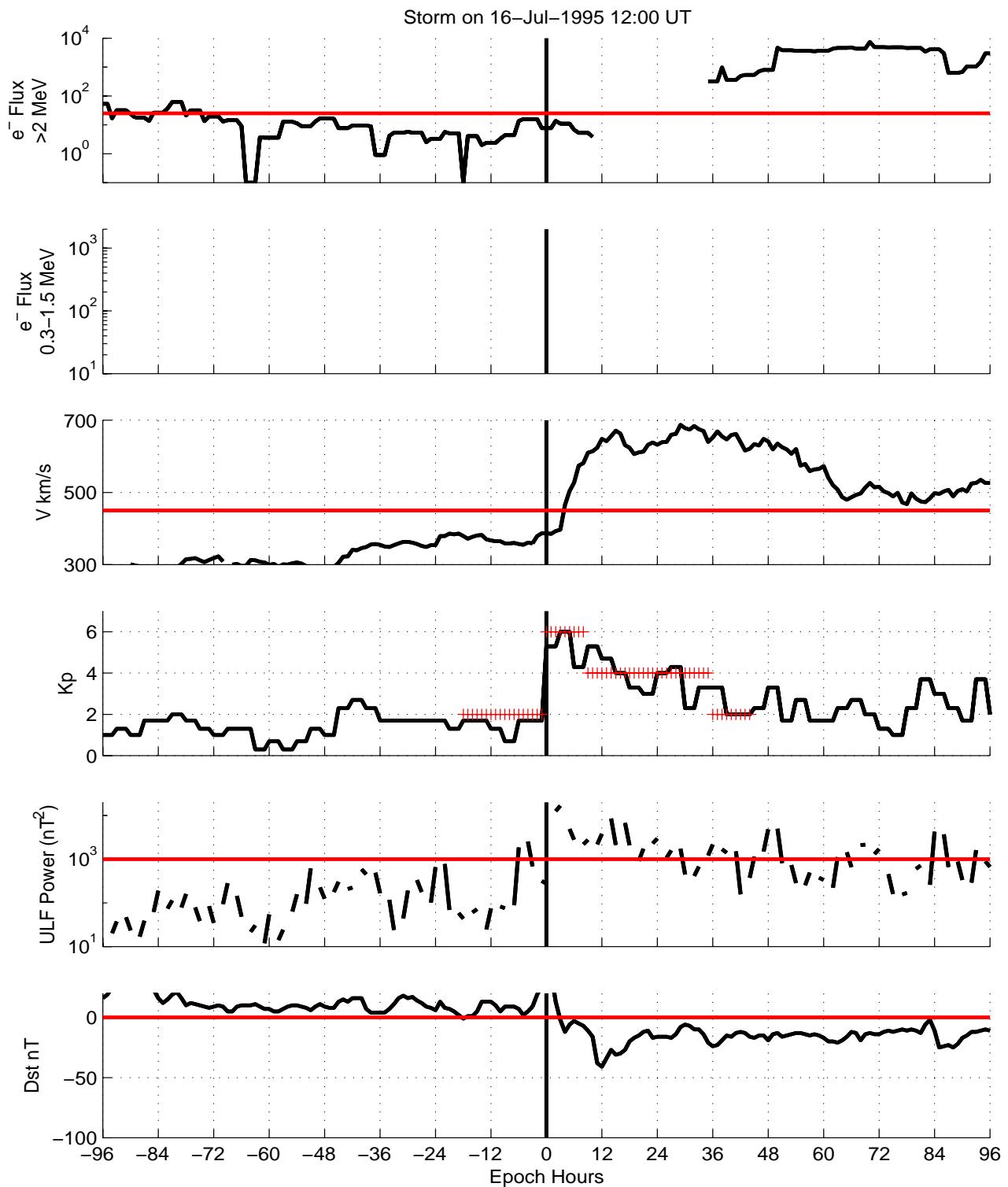
I3. K_p Top Hat Example 1993/06/10



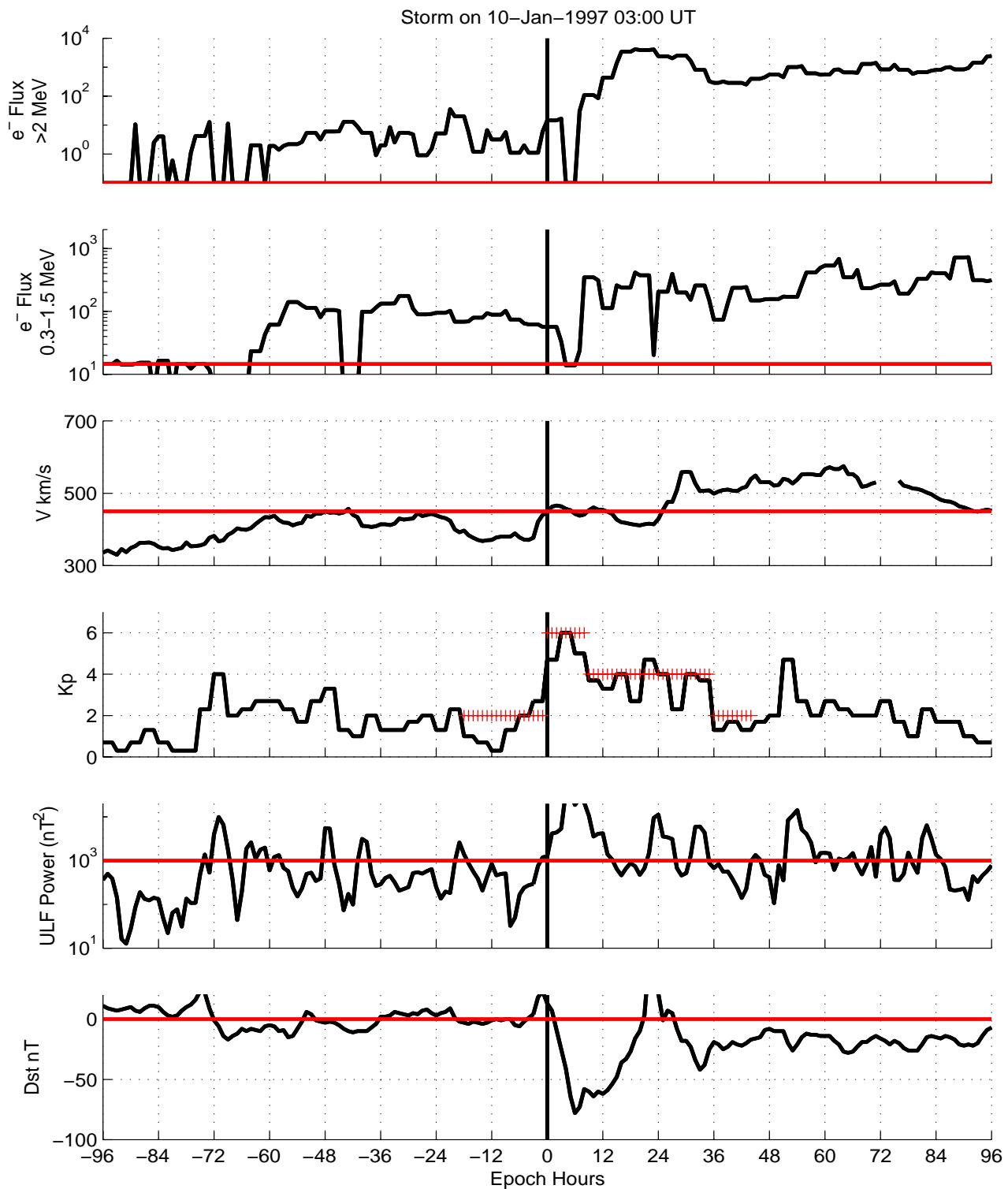
I4. Kp Rise/slow fall Superposed Epoch



I5. Kp Rise/slow fall
Example 1995/07/16

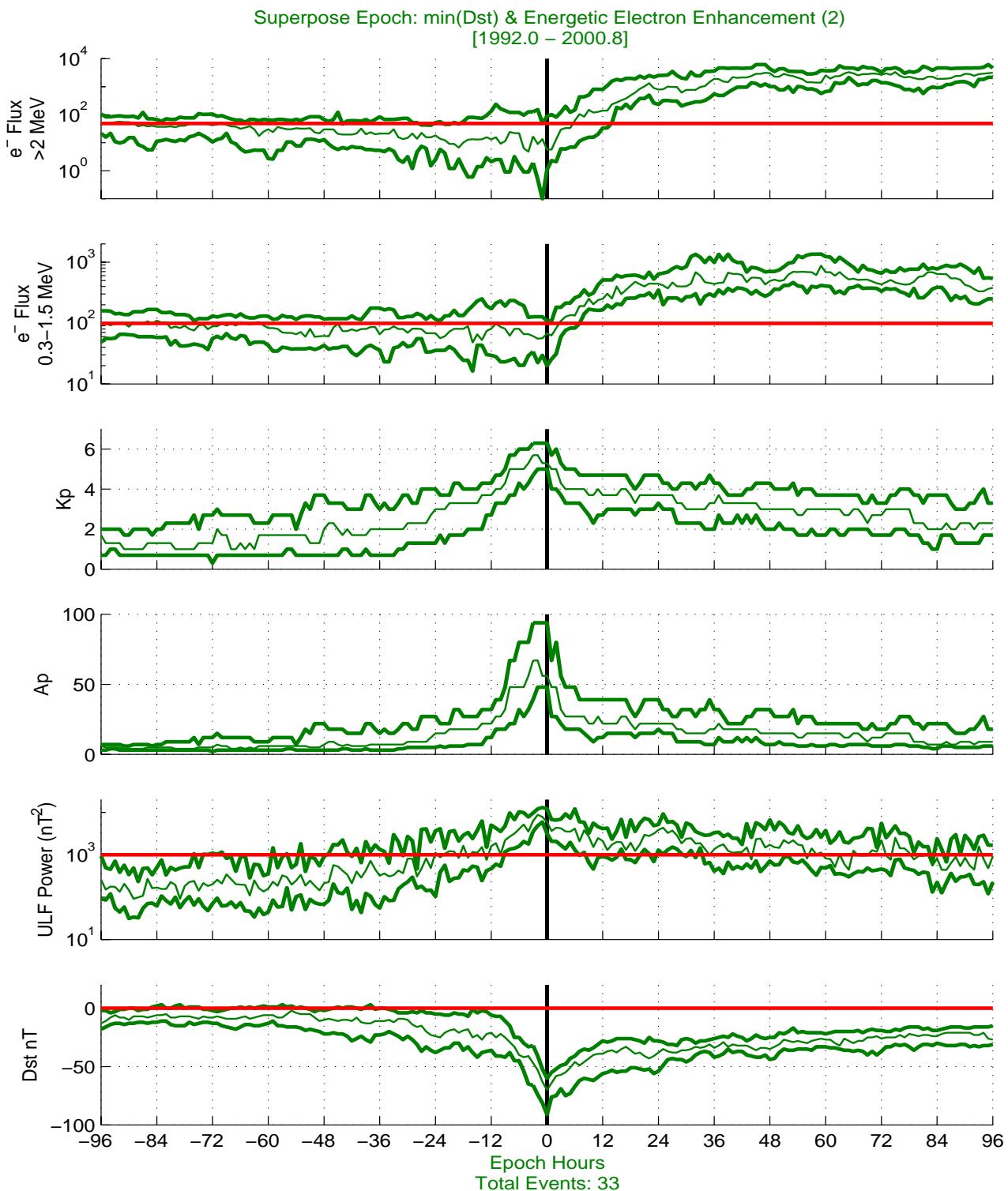


I6. Kp Rise/slow fall
Example 1997/01/10



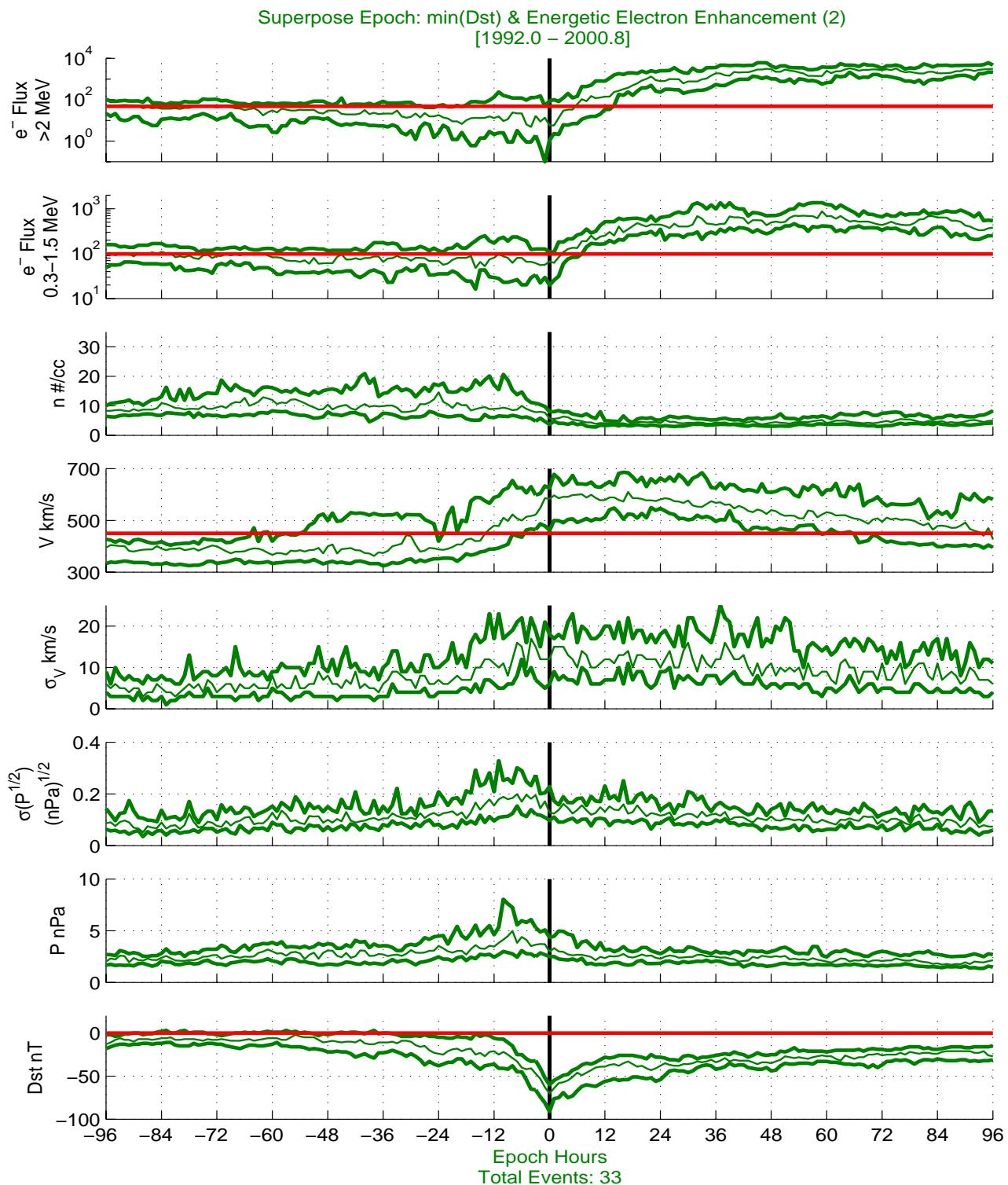
J1.

Superposed Epoch ULF waves storm, Rel. Elec.



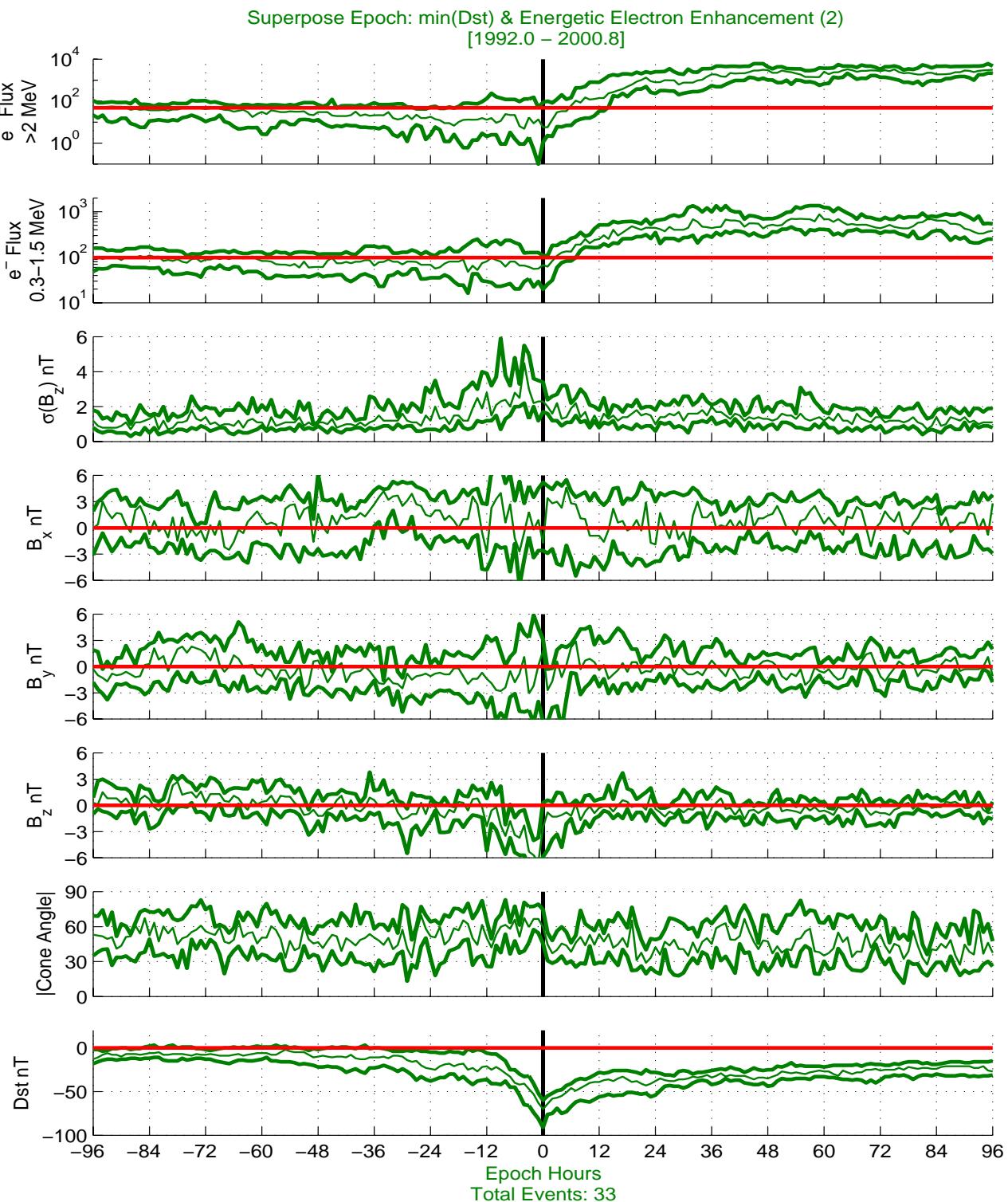
J2.

Superposed Epoch ULF waves storm, Rel. Elec.



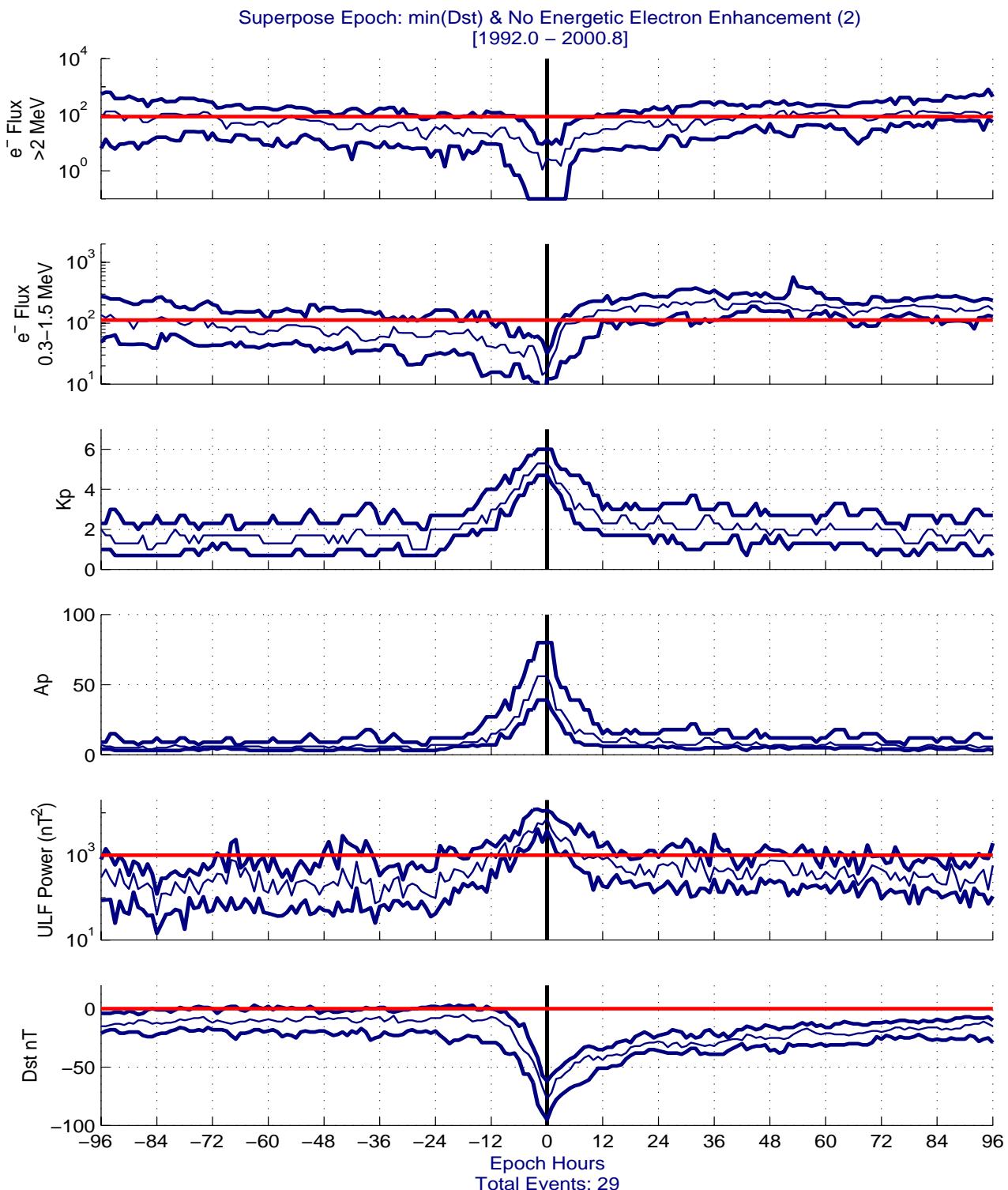
J3.

Superposed Epoch ULF waves storm, Rel. Elec.



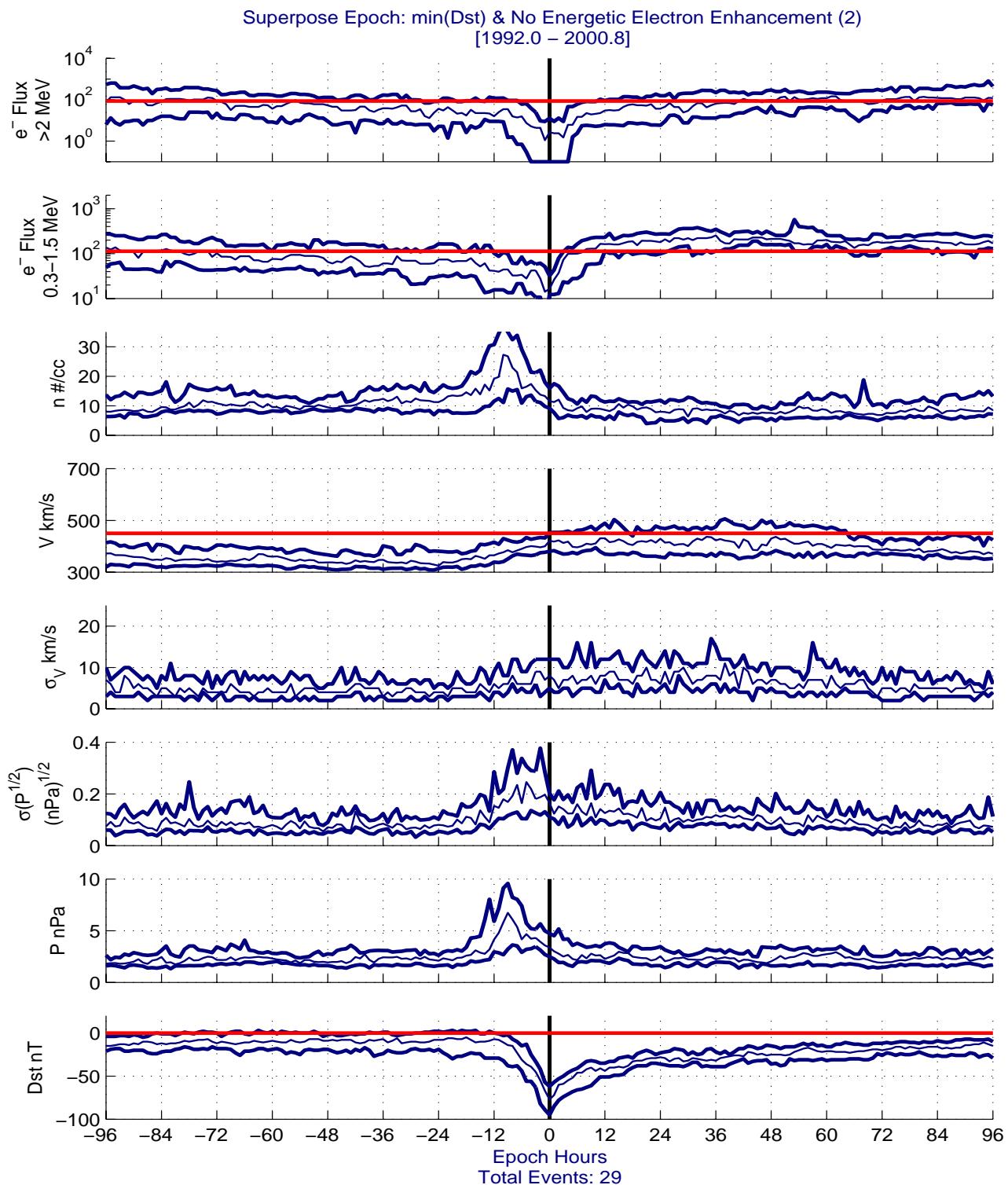
J4.

Superposed Epoch ULF waves storm, no Rel. Elec.



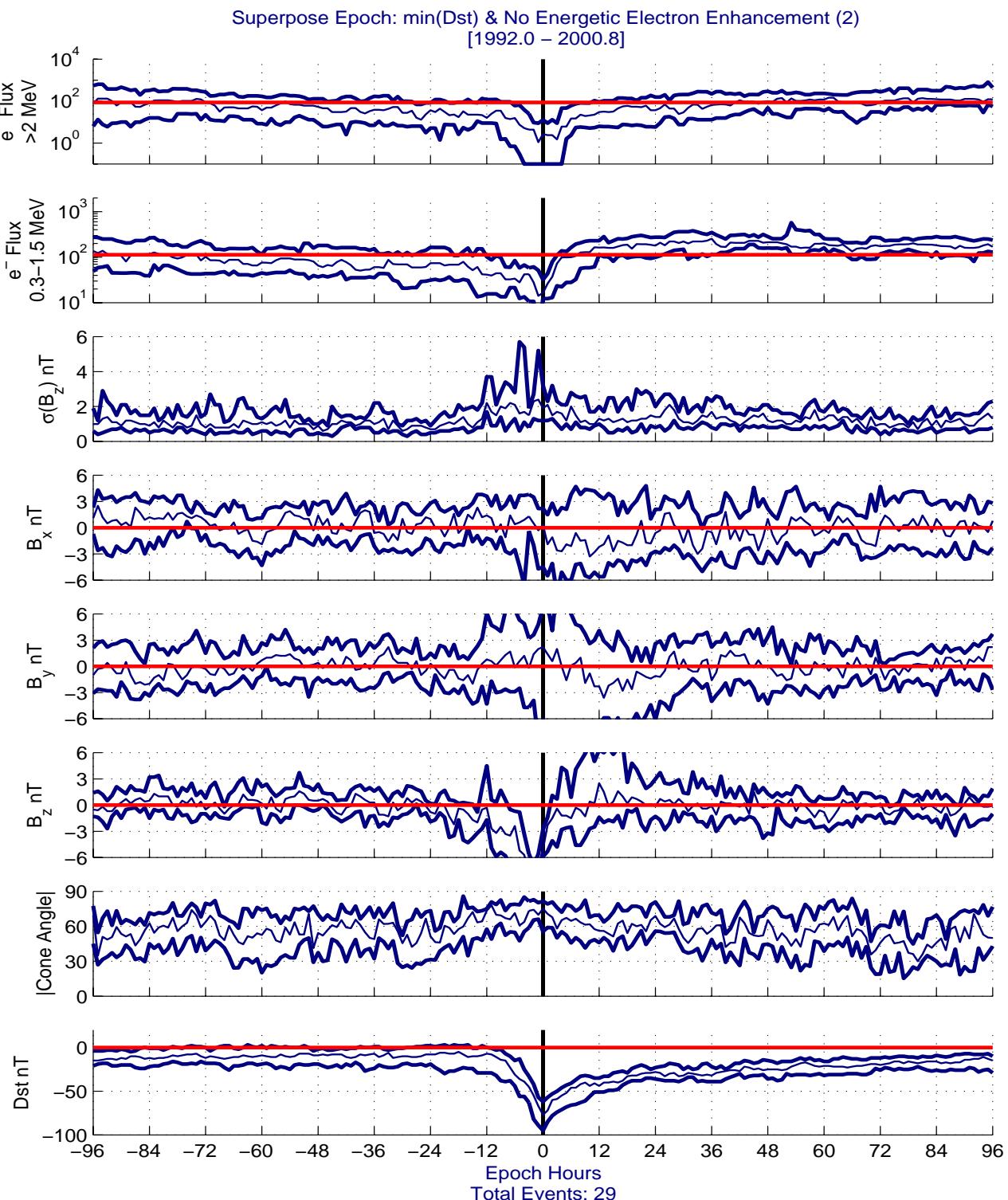
J5.

Superposed Epoch ULF wave storm, no Rel. Elec.



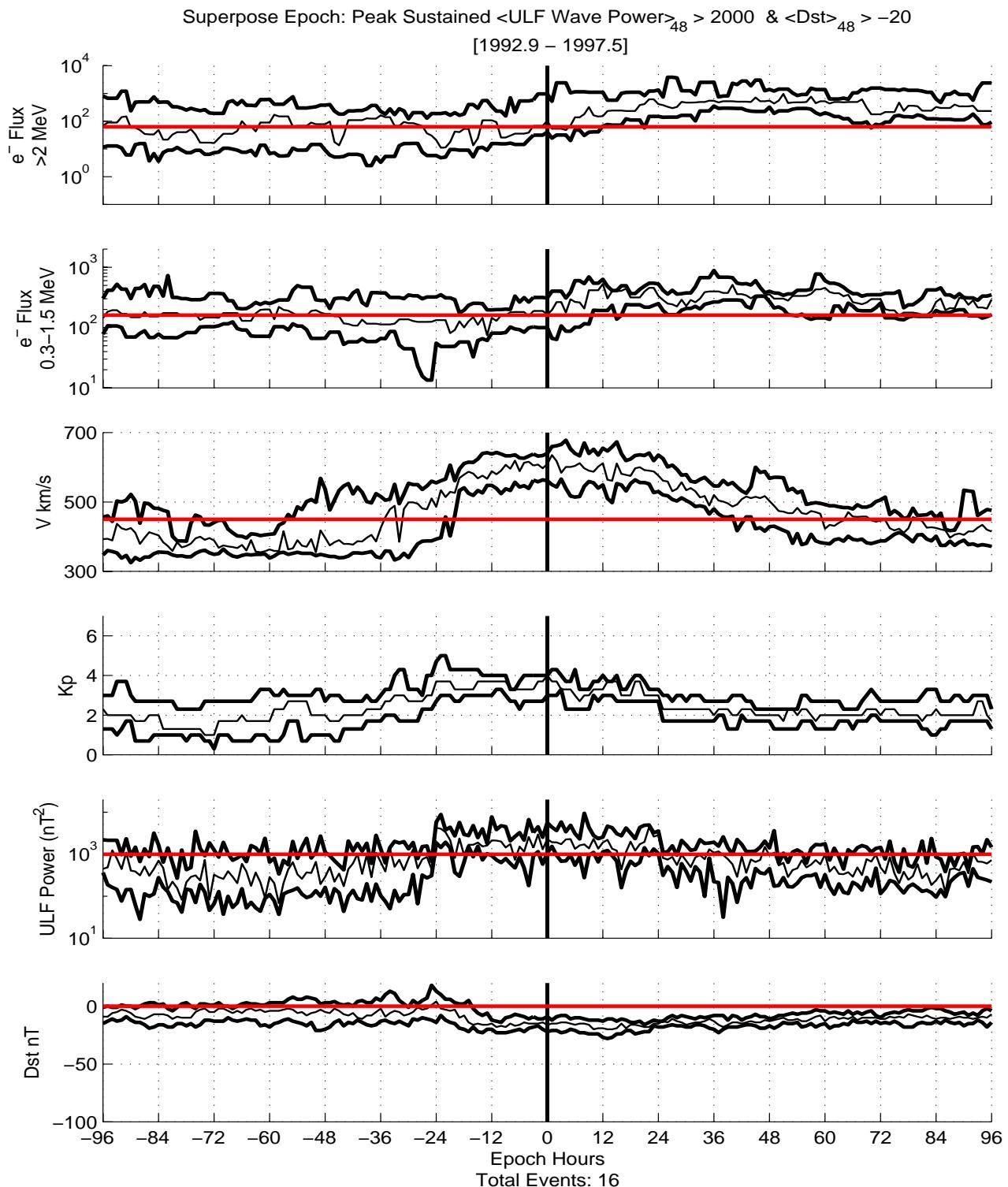
J6.

Superposed Epoch ULF waves storm, no Rel. Elec.



J7.

Superposed Epoch ULF waves no storm, Rel. Elec



K. Summary



- Salammbô code can reproduce general feature of individual storms using Kp-dependent diffusion + recirculation at plasmapause.
- Salammbô needs extension to include losses - can obtain these from GPS data at 1 hour resolution.
- Salammbô operation can be used to explain predict a wide variety of storms based on Kp profile alone.
- ULF waves clearly also an important factor
- Solar wind speed contribution to pressure more geo-effective than density.
- Time integrated effect needed for effective ULF waves.
- ULF waves alone, during “no-storm” periods, also produce relativistic electrons!